INTRODUCTION

This Training Manual presents a knowledge base extracted from 10CFR's, the MURSOM, NRC Regulatory Guides and the like, upon which isotope workers may build. Basic understanding of knowledge selected from such documents for job-specific training must be certified by oral or written examination with results on file with the URSO.

Marshall University personnel working in isotope restricted facilities must demonstrate an appropriate level of knowledge, combined here, in order to comply with NRC License conditions, and MURSOM, 10CFR and State of West Virginia Bureau of Public Health, Radiological Division regulations. Additional information on the University's Radiation Protection Program is available in the MURSOM or at the URSO.

Persons designated as Authorized Users under the provisions of 10 CFR 33.17(b) and Condition No. 12 of the NRC License meet the training criteria of 10 CFR 33.15(b) as a minimum. 10 CFR 19.12 requires that persons who work in or frequent any portion of a restricted area must be informed of the presence of licensed material and the precautions to protect against potential hazards. Accordingly, this training manual is provided as a resource in our program to train and retrain involved individuals as needed. The information in this program is tailored to assist in training various types of workers such as radiation safety staff, Authorized Users, radiation workers, animal caretakers, and ancillary staff including housekeeping and maintenance.

This program also includes a review of emergency procedures and, when appropriate, includes checks of trainee performance and understanding.

Training of individuals is ensured by a commitment to:

1. determine trainee understanding of instruction by written or oral examination or other suitable means;
2. provide for maintaining records of those trained with results submitted to the URSO, and
3. retrain personnel at least annually or when substantial program changes have occurred.

YOUR RESPONSIBILITIES AS RADIOISOTOPE WORKERS

Your responsibilities include the following:

YOU MUST:

- Be familiar with the radiochemicals you are using; know their radiological, physical and chemical properties, methods of detection, the types of hazards that each one presents, etc.
- Be fully knowledgeable of the specific precautions and handling requirements for each isotope you use and of the precautions to be followed with radioisotopes in general.
- Be certain of what is permitted by the license under which you are working. All conditions for radioisotope use as set forth in the Application for Use of Radioisotopes must be adhered to, and no deviations are permitted without first amending the Application.
- Inform co-workers and visitors to your isotope areas of the presence of radioactive material and of any precautions they should take.
- Maintain appropriate monitoring and inventory records.
- Know how to properly use your survey meter(s), as needed.
- Know how to use film badges and/or ring dosimeters (if needed).

TYPES OF RADIATION:

Radiation can be defined as energy which is transmitted thru space in wave or energetic particle form, and includes such things as visible light, ultraviolet light, microwaves, radio waves, laser light and infrared radiation. Although there can be hazards associated with these forms of radiation, the main topic of this booklet is ionizing radiation. Ionizing radiation is that radiation which has sufficient energy to break chemical bonds by "ionizing" atoms, i.e. enough energy is imparted to the atom to knock an electron out of its orbit around the nucleus.

Ionizing radiations include alpha particles; two types of beta particles; accelerated electrons, protons, or other charged particles; gamma and x-rays; and neutrons. The types which you will most likely deal with are alpha ((), beta ((), gamma (() and/or x-ray radiation. The energy of the radiations may often be expressed in units of electron-volts (eV), or a multiple of eV such as kilo-electron-volts (keV) or mega-electron-volt (MeV). The damage caused by ionizing radiation depends on the type of radiation and its energy.

Alpha particles are physically the same as fast helium nuclei, consisting of 2 protons and 2 neutrons and carrying 2 positive electrical charges. Alphas originate in the nucleus of some of the heavier radioisotopes and usually have energies which range from 4 to 8 million electron volts (MeV). Alphas have very limited penetrating ability and can be stopped by a sheet of paper or the dead outer layer of skin and hence are not considered an external radiation hazard. However, since they are high energy charged particles, they produce a very large number of ionizations along the short distance they travel. They can therefore be a very serious internal hazard (for example, to the lung and tracheobronchial region), and precautions should be taken to avoid inhalation, injection, or ingestion.

Negative beta particles are essentially fast moving electrons which originate from the nucleus of certain radioactive isotopes and carry a single electrical charge. Negative betas are often called just "betas", while positive charged betas are called positrons. Betas are generally less energetic than alphas, but some isotopes emit betas with maximum energies at MeV levels. Betas generally penetrate further through matter than alphas do and can therefore present an external hazard. Whether a beta emitting radioisotope presents an external hazard depends on the maximum energy of the betas emitted. For example, H-3, C-14, Ca-45, and S-35 emit relatively low energy betas and do not present much of an external hazard. However, P-32, which emits betas up to 1.71 MeV, can be a serious external hazard. All beta emitters (in fact, all radioisotopes) do present an internal hazard and precautions against inhalation, absorption through skin or wounds, injection, or ingestion must be observed.

Gamma rays and x-rays are electromagnetic radiations which are essentially the same, differing only in that gamma rays originate in the nucleus of an atom, whereas x-rays arise outside the nucleus. Both can be considered as "mass less" quanta, or packets, of energy. They are similar to light photons but have greater energy and are invisible.

Most gamma emitting nuclides emit photons with energy less than 2 MeV. Gamma and x-rays are more penetrating types of radiation and present the most common external hazard. One should take steps to minimize external exposure, while also taking care to avoid internal contamination.

"Bremsstrahlung" is the name given to x-ray type radiation produced when beta particles are absorbed in a medium. As the beta is slowed down, some of its energy is emitted as x-ray radiation. The energy and intensity of this bremsstrahlung increases respectively with increasing energy of the beta and with increasing atomic number of the absorbing medium. For small quantities of "soft" beta emitters like C-14, the energy is low enough that the bremsstrahlung produced is inconsequential. For isotopes like P-32, however, the bremsstrahlung has greater range (penetrating ability), and can present a more serious external deep dose hazard than the betas. (See the discussion on Shielding on page 19)

UNITS AND TERMS: (Also see Section on Definitions)

The following is a list of some of the most common radiation units and terms. Other terms are defined in the pages at the end of this training document.

Activity: The activity of radioactive material refers to the number of atoms disintegrating per unit time and not necessarily to the number of particles given off per unit time by the radionuclide.

The special unit of activity is the curie (Ci)

1 Curie (Ci) = 2.22 x 1012 disintegrations/minute (dpm) = 3.7 x 1010 disintegrations/second (dps)

1 milliCurie (mCi) = 2.22 x 109 dpm = 3.7 x 107 dps = 0.001 Ci

1 microCurie ((Ci) = 2.22 x 106 dpm = 3.7 x 104 dps = 0.001 mCi = 0.000001 Ci

1 picoCurie = 2.22 dpm = 3.7 x 10-2 dps = 0.000001 (Ci = 0.000000001 mCi = 0.000000000001 Ci

In the International System of Units (SI), activity is given in Becquerel (Bq):

1 Becquerel (Bq) = 1 dps = 0.000027 (Ci

Also note that the special unit may be expressed in the SI unit using the relationships:

1 Ci = 37.GBq 1 mCi = 37.MBq 1 (Ci = 37.kBq

Exposure: This expresses the amount of ionization (electrical charge) produced by x- or gamma radiation in a defined mass of air.

The special unit of exposure is the roentgen (R). For example:

1 roentgen (R) = 1R = 2.58 x 10-4 coulombs/kg air, or 1 roentgen = 1R = 1 esu/cc of air (at STP) 1 milliroentgen (mR) = 1/1000 R = 0.001 R

There is no special unit for exposure in the SI system, and coulombs/kg is used exclusively.

Absorbed Dose: Describes the amount of energy imparted to matter by ionizing radiation. The absorbed dose in a region is determined by dividing the energy absorbed in that region by the mass of the matter in that region. The special unit of absorbed dose is the rad. A roentgen (1R) of x or gamma radiation, in the energy range 0.13-3.0 MeV, produces 0.96 rad in soft tissue. Thus, for many purposes, values of exposure in roentgens are usually considered as numerically equal to absorbed doses in rads to tissue irradiated at the same point.

1 rad = 6.24 x 107 MeV per gram, or

1 rad = 100 erg/gm = 0.01 J/kg

1 millirad = 1/1000 rad = 0.001 rad

In SI units:

1 gray (Gy) = 100 rads = 1 J/kg

1 rad = 0.01 Gy = 10 milliGray (mGy)

Dose Equivalent: Although the injury in living systems produced by a given type of ionizing radiation depends on the amount of energy imparted, some types of particles produce greater damage than others for the same amount of energy imparted. When the absorbed dose in rads is evaluated for purposes of radiation protection, it must be multiplied by a "quality factor" and any other modifying factors that may be justified. The resultant quantity, which now takes into account the relative ability of different types of radiation to produce damage in a person, is known as the dose equivalent.

The special unit of dose equivalent is the rem, originally an acronym for roentgen equivalent in man.

1 rem = absorbed dose (rads) x QF

1 mrem = 1/1000 rem = 0.001 rem

Since the quality factor for x-, gamma and most beta radiation equals 1, the general "rule of thumb" for radiation protection, is that a roentgen is a rad is a rem, i.e. 1R = 1 rad = 1 rem.

In SI units, the special unit of dose equivalent is the sievert:

1 sievert (Sv) = 100 rems, or

1 rem = 0.01 Sv = 10 mSV

Table 1 shows some common quality factors.

Table 1

Quality Factor for Various Radiations

RADIATION	QF
Gamma-rays	1
X-rays	1
Beta-rays and electrons of energy >0.03 MeV	1
Beta-rays and electrons of energy 0,03 MeV	1.7
Thermal neutrons	2
Fast neutrons (unknown energy)	10
Protons (high energy)	10
Alpha-rays	20
Heavy ions	20

Half-Life: The term half-life refers to the time it takes for half of a given sample of radioisotope to decay. The half-life of an isotope is unique to that isotope and does not readily change regardless of the physical or chemical environment of the sample of radioisotope. (Extreme pressure can reportedly influence the half-life of a form of decay called electron capture).

Half-life can be used to determine the Activity (A) at time "t" relative to the activity at time "0" by the following equation.

At = Aoe-(0.693(t)/T)

where At = activity at time t

Ao = activity at time 0

t = time

T = half-life

Note: both time "t" and half life "T" must both be given in the same units, but can be sec, hr, min, da, yr, etc.

Ao and At are given in the same units but can be dpm, Bq, Ci, mCi, cpm, etc.

Counting Efficiency: The counting efficiency of a radiation detector is a measure of the detector's ability to record a count when radiation is incident upon the detector. The efficiency varies from detector to detector, and for any single detector, efficiency may vary with the isotope being counted, the physical and/or chemical characteristics of the sample, the geometry of the counting set up, the condition of the detection system components, etc.

Often, a known quantity of the radioactive material to be counted (i.e., a radioactive "standard") is counted under conditions as similar to the usual sample counting conditions as possible. In many cases, a more convenient radioisotope (e.g. one with a longer half-life than the actual isotope to be counted) which emits radiation very similar to the sample isotope may be used. Such a standard is usually referred to as a "mock" standard.

Percent efficiency may be determined from the formula:

Efficiency (%) = count rate above background x 100%/ Standard decay rate

The count rate measured for the standard is entered into the numerator, and the known disintegration rate is entered into the denominator. For example, if a standard containing 10,000 dpm of a radioisotope is counted and the detector yields a net 1000 cpm, the detector is 10% efficient for that isotope under the particular counting conditions. Note that time units for the count rate and decay rate must be consistent. Both numerator and denominator must be expressed over the same time period such as "per minute". If the decay rate is in Becquerels, then the count rate must be in counts per second.

It is sometimes useful to express a counter's efficiency in terms of count rate per activity (e.g. cpm/(Ci). This is sometimes referred to as detector "sensitivity" and is determined in the same way as percent efficiency - that is, by actually counting a standard of known activity.

In many cases, you must know the efficiency of your detection system. U.S. Nuclear Regulatory Commission (NRC) requirements dictate that the results of any smear or wipe survey be reported in terms of activity (dpm per 100 cm2). For a given isotope, cpm or cps depend on the counting system and are not acceptable for recording survey results. A detector's efficiency can change from day-to-day or even hour-to-hour, so counting efficiency should be determined often, ideally for each set of samples you count. Contact the Radiation Safety Office if you need assistance in determining your counter's efficiency.

BACKGROUND RADIATION AND NON-OCCUPATIONAL EXPOSURE

Before any discussion of health risks and radiation dose limits, it is useful to understand the levels of radiation we are all exposed to, regardless of our occupations.

One important component of our exposure to ionizing radiation comes from natural background radiation. Every human being, and in fact every living thing, who has ever existed on planet earth has been exposed to radiation from naturally occurring sources. The three types of sources of whole body background radiation and the average levels of exposure from each to U.S. residents are listed in Table 2.

These are average doses, and world-wide the annual dose range may vary from 75 to 700 millirem depending on geological, geographical, and other local factors.

Table 2*

Average Annual Dose

Terrestrial - radiation from soil and rocks	50 millirem DDE
Cosmic - radiation from outer space	50 millirem DDE
Radioactivity normally found within the human body	25 millirem EDE

TOTAL	125 millirem

*Source NRC Regulatory Guide 8.13 Rev 2, December 1987

Another important component of background radiation is exposure to radon gas and its radiological decay products. In this case, the exposure is primarily to the lungs as opposed to the whole body, and the dose levels to individuals vary tremendously, even between persons who live in homes that are side-by-side. However, it has been estimated that the average annual lung dose to the US population is on the order of 300 mrem per year.

Additionally, exposure to natural sources may be increased to some degree by our use of technology. For example, the use of caulking and insulation for energy efficiency usually decreases the number of air changes in a home, and may increase radon levels. Another example is flying at high altitudes, where atmospheric shielding of cosmic radiation is reduced. A cross country flight can result in an additional 5 mrem of radiation. Smokers receive an additional radiation dose to some regions of the bronchial epithelium which may be as high as 20,000 mrem per year from naturally occurring alpha emitting isotopes in tobacco smoke.

A second major source of radiation dose to the U.S. population is from the medical exposure of patients. On the average, the U.S. population receives about 100 mrem per year per person as a result of undergoing diagnostic or therapeutic medical procedures such as x-ray or Nuclear Medicine studies. The actual dose to the individual patient varies with the type of study not only with regard to the radiation dose, but with the area of the body exposed. Many x-ray procedures expose only very limited portions of the body to the primary x-ray beam. A list of typical doses from some medical diagnostic tests are found in Tables 3 and 4. The relative contribution of sources of radiation exposure to members of the US population are summarized in the pie chart in Figure 1.

Table 3

Typical X-Ray Doses*

Examination	Mean Active Bone Marrow Dose
Skull	80 mrad
Chest (Radiographic)	10 mrad
Gastro-Intestinal Series	530 mrad
Gallbladder	170 mrad
Barium Enema	880 mrad
Pelvis	90 mrad
Femur	20 mrad
Dental	10 mrad

*From: "The Mean Active Bone Marrow Dose to the Adult Population of the United States from Diagnostic Radiology", by B. Shleien, FDA 77-8013, 1977.

Table 4

Typical Nuclear Medicine Doses* (whole body dose unless otherwise noted)

Lung Perfusion	60 mrad
Thyroid Imaging	140 mrad
Bone Scan	130 mrad
Cardiac Function (Ventriculogram)	280 mrad
Cardiac Stress	640 mrad
Lung Ventilation	70 mrad (lung)
Renal Scan	60 mrad
Brain Imaging	120 mrad

*Derived from dosimetry estimates made by the radiopharmaceutical manufacturers.

BIOLOGICAL EFFECTS

Since ionizing radiation can break chemical bonds, it has the potential for damaging cells and cell molecules like DNA. Biological effects can be considered to be of two major types-- somatic effects (those affecting the individual irradiated) and genetic effects (affecting future generations). Genetic effects refer to the build up of deleterious genes in the population as a result of exposure to radiation. Furthermore, somatic effects can be considered as being both short term and long term. Short term, or prompt, effects include erythema or radio-dermatitis, epilation (hair loss), hematological changes, and other characteristics of the acute radiation syndrome. Prompt effects generally result from acute, large doses (e.g. 100 rad or more delivered within a few hours). Exposure to doses large enough to produce acute radiation syndrome is highly unlikely in biomedical type research labs and in routine clinical use of radioisotopes. Long term or delayed effects include increased risk of cancer and cataracts, embryological effects, and a general shortening of life span. The current assumption is that any exposure, no matter how small, has some degree of risk associated with it, though of course this risk may be very small. (See Cancer and Other Health Risks page 13). Table 5 (page 11) lists some biological effects and the approximate doses at which they occur.

RISKS TO THE EMBRYO OR FETUS

Since 1906, it has been known that rapidly dividing cells and cells that are undifferentiated in their structure and function are more sensitive to radiation. As the embryo or fetus contain large numbers of cells that are undifferentiated and/or rapidly dividing, it would be expected that the embryo/fetus be very radiosensitive, and there is direct evidence that this is so. Additionally, there are periods during pregnancy when the embryo/fetus seems to be especially sensitive, especially during the first 2-3 months, when a woman may not be aware that she is pregnant.

The effects that would be observed in children exposed during the fetal and embryonic stages of development include birth defects (teratogenic effects) such as damage to the nervous system. Severe structural malformations have not been observed in cases where the acute exposure to the embryo or fetus is less than 10 rads.

Potential serious effects include the induction of childhood cancer, mental retardation and abnormal smallness of the head (microcephaly). Table 6 lists some radiation and non-radiation pregnancy risk factors.

Because of the special concern for the developing embryo/fetus, the National Council on Radiation Protection and Measurement (NCRP) recommends that the developing fetus not receive a radiation dose from occupational exposure of the mother of more than 0.5 rem during the entire gestation period. Please note that the "500 mrem during gestation" level is a recommendation for guidance and is not intended as a regulatory limit which may interfere with a woman's right to privacy or right to work. It becomes a regulatory limit if the woman chooses to declare her pregnancy in writing to her employer, including the estimated date of conception. This declaration is usually made thru the Radiation Safety Office. For more information, see Regulatory Guide 8.13 Instructions Concerning Prenatal Radiation Exposure (US Nuclear Regulatory Commission), available from the Marshall University Radiation Safety Office. Pregnant and potentially pregnant women should schedule a one-to-one session with the Radiation Safety Officer for more detailed instructions/information on this topic.

It should be pointed out that, by following the established safety practices for working with radioisotopes, most MU women employees should be able to continue their regular duties with a resulting fetal dose of much less than 500 millirem, in most cases "background". Nevertheless, for certain jobs and/or personnel groups, a temporary lateral transfer to other duties may be recommended, or mandated to comply with the fetal dose limits for a declared pregnant woman.

Table 5

Biological Effects of Radiation

Exposure	Significance
1 rad, major portion of bone marrow	Risk of occurrence of leukemia is about in 10,000
1 rad, whole body	Risk of eventual appearance of cancer about 2-4 in 10,000 (normal incidence from all causes is about 1 in 3)
10 rem, whole body	Elevated number of chromosome aberrations in peripheral blood; no detectable injury or symptoms
20 rad, reproductive system	Dose for doubling spontaneous mutations (lowest of proposed values)
1 rad, reproductive system, prior to conception	Estimated 5-75 additional genetic disorders per million live births. Normal incidence of serious genetic disorders from all causes is 90,000 per million live births. (No such effect has ever been actually observed in humans.)
150 rem, single dose, whole body	Mild radiation sickness
450 mrem, single dose, whole body	Approximately 50% of exposed individuals will not survive, even with the best care
200-300 rad, locally to skin	Epilation
> 300 rad, locally to skin	Radiation dermatitis and erythema
1000-2000 rads to skin	Transdermal injury
> 2000 rads to skin	Radionecrosis
200-500 rads, locally to eye, single exposure	Threshold dose, cataract induction (after latent period)

1000-2500 rads, local, at 200-300 rads per day	Treatment of markedly radiosensitive cancer
2500-5000 rads, local, at 200-300 rads per day	Treatment of moderately radiosensitive cancer

Table 6

Effect	Numbering Occurring from Natural Causes	Risk Factor	Excess Occurrences from Risk Factor
RADIATION RISKS			
		Childhood Cancer	
Cancer death in children	1.4 per thousand	Radiation dose of 1000 millirems received before birth	0.6 per thousand
		Abnormalities	
		Radiation dose of 1000 millirads received during specific periods after conception:	
Small head size	40 per thousand	4-7 weeks after conception	5 per thousand
Small head size	40 per thousand	8-11 weeks after conception	9 per thousand
Mental retardation	4 per thousand	8-15 weeks after conception	4 per thousand
NON-RADIATION RISKS			
		Occupation	
Stillbirth or spontaneous abortion	200 per thousand	Work in high-risk occupations	90 per thousand
		Alcohol Consumption	
Fetal alcohol syndrome	1 to 2 per thousand	2-4 drinks per day	100 per thousand
Fetal alcohol syndrome	1 to 2 per thousand	More than 4 drinks per day	200 per thousand
Fetal alcohol syndrome	1 to 2 per thousand	Chronic alcoholic (more than 10 drinks per day)	350 per thousand
Perinatal infant death (around the time of birth)	23 per thousand	Chronic alcoholic (more than 10 drinks per day)	170 per thousand
		Smoking	
Perinatal infant death	23 per thousand	Less than 1 pack per day	5 per thousand

From: USNRC Regulatory Guide 8.13, (Revision 2) Instructions Concerning Prenatal Radiation Exposure

CANCER AND OTHER HEALTH EFFECTS

The cancer risk estimates presented in Table 7 were developed by the National Academy of Science Advisory Committee on the Biological Effects of Ionizing Radiation (BEIR), the International Commission on Radiological Protection (ICRP) and the United Nations Scientific Council on the Effects of Atomic Radiation (UNSCEAR).

It is important to realize that these risk numbers are only estimates. Many difficulties are involved in designing research studies that can accurately measure the small increases in cancer cases due to low exposure to radiation as compared to the normal rate of cancer. There is still uncertainty and a great deal of controversy with regard to estimates of radiation risk. The numbers used here result from studies involving high doses and high dose rates, and they may not apply to doses at the lower occupational levels of exposure. They are based on a simple linear extrapolation from available data for high doses received over short time periods to low doses received over long time periods. In other words, these estimates assume that the risk per unit rem dose as determined for high, short term doses will be the same at low, occupational dose levels. Furthermore, these estimates also assume that there is no threshold level of radiation exposure below which there is no health risk. The NRC and other agencies both in the United States and abroad are continuing extensive long-range research programs on radiation risk.

Table 7

Estimates of Excess Cancer Incidence from Exposure to Low-Level Radiation*

Source	Number of Additional** Cancers Estimated to Occur in 1 Million People After Exposure of Each to 1 Rem of Radiation
BEIR III, 1980	160-450***
ICRP, 1977	200
UNSCEAR, 1977	50-350

**"Additional" means above the normal incidence of cancer.

***All three groups estimated premature deaths from radiation-induced cancers. The American Cancer Society has recently stated that only about one-half of all cancer cases are fatal. Thus, to estimate the incidence of cancer, the published numbers were multiplied by 2. Note that the three groups are in close agreement on the risk of radiation-induced cancer.

*From: Regulatory Guide 8.29 July 1991, U.S. NRC

Some members of the National Academy of Sciences BEIR Advisory Committee (BEIR III, 1980) and others feel that risk estimates in Table 7 are higher than would actually occur and represent an upper limit on the risk. Other scientists believe that the estimates are low and that the risk could be higher. However, these estimates are considered by the NRC to be the best available that the worker can use to make an informed decision concerning acceptance of the risks associated with exposure to radiation. A worker who decides to accept this risk should make every effort to keep exposures to radiation As Low As Reasonably Achievable (ALARA) to avoid unnecessary risk. The workers, after all, have the first line responsibility for protecting themselves from radiation hazards.

In an effort to explain the significance of the estimates in Table 7, assume an approximate average of 300 excess cancer cases per million people, each exposed to 1 rem of ionizing radiation. Using a linear, no threshold, risk model, if a group of 10,000 workers each receives 1 rem, we would estimate that three would develop cancer because of that exposure, although the actual number could be more or less than three.

The American Cancer Society has reported that approximately 33 percent of all adults in the 20 to 65 year age bracket will develop cancer during their lives from all possible causes such as smoking, food, alcohol, drugs, air pollutants, and natural background radiation. Thus, in any group of 10,000 workers not exposed to radiation on the job, we can expect about 3,300 to develop cancer. Again using a linear extrapolation of risk from high dose data, if this entire group of 10,000 workers were to receive an occupational radiation dose of 1 rem each, we could estimate that three additional cases might occur, which would give a total of about 3,303. This means that a 1 rem dose to each of 10,000 workers might increase the cancer rate from 33 percent to 33.03 percent, an increase of about 3 hundredths of one percent.

Another useful unit for comparison among health risks is the average number of days of life expectancy lost per unit of exposure to each particular health risk. Estimates are calculated by looking at a large number of persons, recording the age when death occurs from apparent causes, and estimating the number of days of life lost as a result of these early deaths. The total number of days of life lost is then averaged over the total group observed. The person who gets cancer may loose several years of life, while others loose no days at all.

Several studies have compared the projected loss of life expectancy resulting from exposure to radiation with other health risks. Some representative numbers are presented in Table 8.

Table 8

Estimated Loss of life Expectancy From Health Risks*

Health Risk	Estimates of Days of Life Expectancy Lost Average
Smoking 20 Cigarettes/Day	2370 (6.5 years)
Overweight (by 20%)	985 (2.7 years)
All Accidents (combined)	435 (1.2 years)
Auto Accidents	200
Alcohol Consumption (US Average)	130
Home Accidents	95
Drowning	41
Natural Background Radiation (calculated)	8
Medical Diagnostic X-rays (US average, calculated)	6
All Catastrophes (Earthquake, etc.)	3.5
1 Rem Occupational Radiation Dose (calculated; Industry Average for the Higher-Dose Job Categories is 0.65 Rem/Year	1
1 Rem/Year for 30 Years (calculated)	30

*Adapted from Cohen and Lee, "A Catalog of Risks", Health Physics, Vol 36, June 1979 and used in Regulatory Guide 8.29, July 1991 by the U.S. NRC

Another way of comparing various health risks is to look at different activities (or levels of activities) that produce the same statistical risk. Table 9 compares activities which have a "one in a million" chance of producing a fatality. The 10 mrem of radiation shown is approximately equal to the dose from a chest x-ray, is 1/500th the annual occupational dose limit, and is about 1/10th of our annual dose from natural background sources.

These estimates indicate that the health risks from occupational radiation exposure are smaller than the risks associated with many other events or activities we encounter and accept in our normal day-to-day lives.

Table 9

Risks which Increase Chance of Death By 1 in a Million

* 10 mrem to the whole body * Smoking 1.4 cigarettes * Living with a smoker for 2 months * Living 2 days in Boston * Eating 40 tablespoons of peanut butter * Canoe ride of 6 miles * Bicycle ride of 10 miles * Automobile ride of 300 miles

From "Risks Caused by Low Levels of Pollution", Yale Journal of Biology and Medicine, 51:46, 1978

A third useful comparison is to look at estimates of the average number of days of life expectancy lost from exposure to radiation and from common industrial accidents at radiation related facilities and to compare this number with days lost from other occupational accidents. Table 10 shows average days of life expectancy lost as a result of fatal work related accidents. Note that the data for occupations other than radiation related do not include death risks from other possible hazards such as exposure to toxic chemicals, dusts, or unusual temperatures. Note also that the unlikely occupational exposure at 5 rems per year for 50 years, the maximum allowable risk level, may result in a risk comparable to the average risk in mining and heavy construction.

Table 10

Estimated Loss of Life Expectancy From Industrial Hazards*

Industry Type	Estimates of Days of Life Expectancy Lost Average
All Industry	74
Trade	30
Manufacturing	43
Service	47
Government	55
Transportation and Utilities	164
Agriculture	277
Construction	302
Mining and Quarrying	328
Radiation Accidents Death From Exposure	<1
Radiation Dose of 0.65 Rem/Yr (Industry	

Average) for 30 Years, Calculated	20
Radiation Dose of 5 Rems/Yr for 50 years	250
Industrial Accidents At Nuclear Facilities (Non-Radiation)	58

*Adapted from Cohen and Lee "A Catalog of Risks", Health Physics, Vol 36, June 1979 and World Health Organization Health Implications of Nuclear Power Production, December 1975, Regulatory Guide 8.29, U.S. NRC

In 1990, another BEIR Committee (BEIR V) re-examined a number of issues related to the cancer risk estimates for exposure to low levels of ionizing radiation, including revised dose estimates for the A-bomb survivors on whom much of the risk evaluation is based, and compared differences in the risk models used. The published BEIR V report estimated that, in general, the risk of cancer induction following radiation exposure may be about 3.5 times larger than the higher of their previous estimates (see Table 7). This remains a controversial subject with a good deal of scientific uncertainty, and it may be some time before the new estimates are widely or fully accepted but they are utilized by advisory or regulatory bodies. Nevertheless, it is important to realize that the new estimates are still based primarily on high doses and high dose rates, and the report cautions that for low doses delivered fractionally over a period of time, such as one expects in an occupational setting, animal experiments suggest that the risks are lower, and that continued research is needed in this area. It is also important to note that, even if the risk is four times higher than previously believed, four times a relatively low risk is still a relatively low risk.

LIMITS AND ALARA

Dose limits are designed in principle to limit radiation exposures to a level where the incurred risks are deemed to be "acceptable" by the exposed individual and/or society. Occupational limits are based to a large extent on this idea of an "acceptable risk".

Theoretically, an employee may work all their working life around radiation at the maximum limits and incur health risks no greater than that incurred in many other occupations. At the same time, both the worker and society gain benefits from the use of radiation. However, since it is prudent to assume that there is some risk associated with any exposure to radiation, it is the goal of radiation safety to keep exposures As Low As Reasonably Achievable (ALARA), and any reasonable steps which will lower personnel exposure should be taken. Marshall University has instituted a formal program to maintain radiation exposures ALARA, and you should be familiar with the ALARA philosophy in general and Marshall's program in particular. Generally the ALARA program requires the University to evaluate any radiation exposure approaching 10% of a regulatory limit. If you work safely, it is unlikely that you will reach even 10% of the maximum dose limits. Here at Marshall, radioisotope research laboratory workers generally receive less than 50 mrem/yr, and most such workers seldom, if ever, receive any measurable occupational exposure above that due to natural background radiation. Among clinical workers at local hospitals, there is considerably more variation ranging from low exposure groups (eg. Nursing) to moderate (Nuclear Medicine, (100-300 mrem/year). Nationally, the average occupationally exposed hospital worker (including x-ray workers) receives about 150 mrem annually, but usual levels are far lower. Table 11 lists some current and older regulatory limits.

Table 11

Regulatory Limits for Radiation Exposure

Topic	Old 10CFR20	Current 10CFR20

Occupational whole body, gonads, lens of eye, blood forming organs, head and trunk	1,250 mrem per calendar quarter or 3 rem per quarter within 5(n-18) dose averaging formula	5000 mrem per year with summation of dose equivalents for external deep dose and dose from internally deposited isotopes. Lens of eye 15,000 mrem/yr eye dose-equivalent at 0.3 cm tissue depth
Occupational extremities	18,750 mrem per quarter (75,000 mrem per year)	50,000 mrem per year
Occupational - skin	7,500 mrem per quarter (30,000 mrem per year)	50,000 mrem per year
Occupational -- minors (under 18 years of age)	1/10 of the above levels	1/10 of above levels
Non-occupational, whole body	500 mrem per year, with no dose-rate exceeding 2 mrem in any one hour or 100 mrem in any 7-day consecutive period in any unrestricted area	100 mrem per year with no dose-rate exceeding 2 mrem in any one hour in any unrestricted area
Occupational Exposure of embryo/fetus	No regulations, recommendation only: 500-mrem in the gestational period	500 mrem for gestation period, after voluntary "declaration" of pregnancy by the woman. Otherwise individual occupational limits apply

Internal exposure limits are currently based on the Annual Limit on Intake (ALI) of radioactivity in air or water by inhalation or ingestion. The annual limit on intake (ALI), may be defined as that intake of a radionuclide which alone would irradiate an individual to the dose limit set by the NRC, for each year of occupational exposure. An occupational internal limit that is essentially equivalent to the ALI would result from annually breathing the derived air concentration (DAC) in air for 40 hours each week. A formerly useful concept was to calculate the maximum permissible body burden (MPBB) which could be continually present in the body and not result in a dose above the limit. Some MPBB's are given in the radionuclide data following page 19. (DAC values may be found in NRC Regulations in Appendix B of 10 CFR part 20). New NRC regulations (Part 20) have revised the system and the MPBB is not used for dose assessment. Under the regulations, internal and external radiation dose equivalents must be summed. The total effective dose-equivalent (TEDE) is the result of summing the deep dose-equivalent (DDE) (from external sources) and the committed effective dose-equivalent (CEDE) from internal sources. The newest whole body limits in Table 11 apply to the TEDE number for a calendar year, while the ALI's in Table 12 limit the CEDE.

Table 12

SOME ANNUAL LIMITS ON THE INTAKE (ALI) AND MAXIMUM PERMISSIBLE BODY BURDENS

Nuclide	Critical Organ	MPBB ((Ci)	ALI ((Ci) (intake for 5 rem CEDE in 1 year by ingestion)	
			ORAL	INHALATION
3H (HTO or 3H2O)	Body Tissue	1000	80,000	80,000
14C Compounds	Fat	300	2,000	2,000
32P (most forms)	Bone	6 soluble	600	900
35S	Testis or LLI	90 soluble	6,000	2,000

125I Compounds	Thyroid	6 soluble	40*	60*
45Ca Compounds	Bone	30 soluble	2,000	800

* Limited by 50 rem thyroid CDE

PRINCIPLES OF RADIATION PROTECTION

There are several principles which you should keep in mind in order to work safely with isotopes. These include time, distance, shielding, and containment.

Time: One way to limit exposure is simply to spend as little time as possible in the radiation area. Try to do your work with isotopes in the minimum time necessary to do the job properly. Good pre-planning and preliminary run throughs and rehearsal experiments without actual radioisotopes can help in this regard.

Distance: The radiation intensity from a point source varies inversely with the square of the distance from the source ("Inverse Square Law"). $\frac{I_1}{I_2} = \frac{(d_2)^2}{(d_1)^2}$ I1 is the intensity at a distance d1, from the source and I2 is the intensity at a distance d2 from the source. The value of this principle can not be over emphasized!

This means doubling the distance between you and a point source decreases your exposure by a factor of 4 (for a given length of time). Conversely, halving the distance quadruples your exposure. A simple example shows the importance of distance relative to radiation exposure. Let's say that a pair of tongs allows you to hold a vial of radioactive material 16 cm away from your fingers where the exposure rate is about 8 mR/hr. Now let's say you pick up the vial with your fingers, and assume the vial keeps your fingers about 1 cm from the source inside. The exposure rate to your fingers will be about: $I_{(1cm)} = \frac{(16)^2(8)}{(1)^2} = 2{,}048\ mR/hr$ This is a factor of 256 times the radiation received when the vial is handled with tongs. The values used in the example could easily be found in a research lab -- they're about what you would expect from 1 mCi of I-131.

In clinical areas, use of distance for radiation protection is particularly important when dealing with therapy sources.

Remember: 1) Maintain as great a distance as possible between you and sources which are external radiation hazards (energetic beta, x-ray, or gamma emitting isotopes).

2) Don't pick up unshielded or inadequately shielded sources with your fingers. Use tongs or forceps whenever possible.

Shielding: A third way to reduce exposure is to use shielding. For small quantities of low- energy beta emitting isotopes, shielding is unnecessary. Very few betas would penetrate the dead outer layer of skin. For gamma protection, high density material such as lead generally provides the best shielding choice. The thickness required depends on the energy of the emitted photons and the amount (activity) of material to be shielded. Very little lead is needed for a "soft" (low energy) x-ray or gamma emitter like 125I -- in fact, less than 1 mm of lead will absorb virtually all the photons, whereas, for 131I, this amount of lead would absorb less than half of the photons. In practice, you usually don't have to calculate how much shielding you'll need -- just add increasing thicknesses around your source and measure its effectiveness with a radiation survey meter. If the exposure rate is reduced to an acceptable level, you've got enough shielding.

Since clinically used radioisotopes are typically gamma emitters, use of lead shielding is common in storage and work areas. Syringe and vial shields are required to be used in Nuclear Medicine, and portable bedside or wall shields are often used for implant cases.

As we discussed earlier, high energy beta particles interacting with dense absorbers can produce a significant bremsstrahlung hazard. For this reason, 32P and other high energy beta emitters are shielded first with a low density material like glass or Plexiglass to absorb the betas. Eight millimeters of Plexiglass or similar density material will stop all of the beta particles from 32P. A thin, high density shield such as lead may then positioned to absorb any bremsstrahlung arising in the Plexiglass.

When relying on shielding, be sure that it is both appropriate and adequate. Do not hesitate to consult with the Radiation Safety Office regarding shielding requirements in your area.

Containment: In order to minimize the chance of ingestion, inhalation or absorption of radioisotopes into body, every effort must be made to confine and limit radioactive contamination. There should be designated radioisotope work and storage areas. Containers should be sealed whenever possible. Any container, which contains radioactivity and which will not remain under your immediate control must be labeled as radioactive. Work trays or areas should be covered with plastic backed absorbent material. Wear lab coats and gloves to keep contamination off street clothes and skin. Gloves prevent possible ingestion of materials from contaminated hands or direct skin absorption of some compounds such as tritiated water and radioiodine compounds. Keep your lab coat buttoned. Each facility must conduct its own radiation survey program, in addition to random surveys done by Radiation Safety personnel. These surveys must include dose-rate, and wipe tests when isotopes other than in sealed or discrete forms are used. Written records of all survey results must be maintained (see the University Radiation Safety and Operations Manual (MURSOM) for more details on lab monitoring). Should a radioactive spill occur, care should be taken to confine the radioactivity to the area of the original spill. Radioisotopes in volatile forms, or which may be released by decomposition into volatile products, should be stored in properly functioning fume hoods. Reactions or experiments involving such compounds must be carried out in a hood. Typical examples involve the use of radioiodine as NaI, tritiated water, tritiated sodium borohydride, gases, or any materials released by an experiment into gaseous products such as 14CO2 . Note that any compound can be an inhalation hazard if it becomes airborne as a dust, mist, etc.

RADIATION SURVEY METERS

In radioisotope laboratories, you will in many cases use a survey meter such as a Geiger-Muller (GM) meter for monitoring the incoming packages, lab surfaces, hands and clothing. A thin window GM detector can be useful in finding "soft" beta contamination. A low-energy gamma scintillator probe is a must for detecting the low-energy emissions from I-125 contamination. Most laboratories have a survey meter for their own use, or they share one with a nearby lab. Survey meters are also available for loan from the Radiation Safety Office. You must make the regular use of a survey meter for monitoring a part of your work, unless you are specifically exempted by the RSO from such surveys.

For NRC required dose-rate surveys, depending on the particular application, ionization chamber survey meters are often used. These are especially accurate for making dose-rate measurements above one or two mrem/hr it should be noted that the use of a dedicated performance check source on each day a meter is used is required by regulations for clinical users, and recommended for all labs.

You should know how to operate the particular survey meters available to you and know both their capabilities and limitations. No meters are good for detecting all isotopes under all situations. You should also know when to use your meter and also when a properly calibrated meter is required (e.g., whenever an NRC required measurement is needed). If you need more information on survey meters and their use, Radiation Safety personnel are available to assist.

SIGNS AND LABELS

Regulations specify both the symbol shape and colors to be used in radiation caution signs, labels, and signals. The familiar three-bladed symbol is used in only the prescribed colors of magenta, black, or purple on yellow unless otherwise authorized by an appropriate regulatory body. For example, Department of Transportation shipping labels show the symbol in black, on white (Radioactive I).

The regulations also specify when certain signs and labels must be used. For example, any room or area where radioisotopes are used or stored in sufficient quantities must be labeled with a sign with the radiation symbol and the words "Caution--Radioactive Materials". In practice, the presence of such a sign does not necessarily mean that isotopes are actually present in a given room or area, but only that the room is authorized for such purposes and may contain radioisotopes. It does not necessarily indicate that a significant radiation hazard is present. If there is an accessible area such that an individual could receive more than 5 mrem/hour at 30 cm (1 ft) from a source/surface, a "Radiation Area" sign must be posted. A "High Radiation Area" sign would indicate dose-rates in excess of 100 mrem/hr at 30 cm, and would also require a significant number of controls over the entrance or access points. A "Very High Radiation Area", has dose rates above 500 rads/hr at one meter distance and currently is not found in any University facility

Most containers of radioactive material are also required to bear radiation caution labels which contain sufficient information to permit workers handling or using the containers to take necessary precautions. This usually means the label should at least identify the isotope(s) contained, and the activity(ies) as of a specified date.

While these are the basic requirements for warning sign usage, there are additional requirements for using signs or labels in other specific situations, and there are also some exceptions. For more information, refer to the regulations in 10 CFR Parts 20 and 35 or contact University Radiation Safety Office.

RADIATION SAFETY CONSIDERATIONS FOR COMMONLY USED RADIONUCLIDES

The following Figures 2 - 7 summarize the characteristics and some of the radiation safety considerations of several commonly used radionuclides.

The concepts of Maximum Permissible Concentration (MPC) and Maximum Permissible Body Burden (MPBB) are considered obsolete, but are included for those persons familiar with the old 10 CFR 20 regulations. On January 1, 1994 a newer 10 CFR 20 was implemented by the University as required by the NRC. It uses the concepts of ALI and DAC to limit intakes of radioactive materials based on their chemical form, route of entry, and other factors. ALI and DAC are discussed on pages 15 and 16 of this document, and values for them are listed in 10 CFR 20 Appendix B to paragraphs 20.1001 - 20.2401.

More detailed information on these and other radionuclides is available from a variety of sources, including the University Radiation Safety Office.

Figure 2 3H (Hydrogen-3, Tritium)

PHYSICAL CHARACTERISTICS

Half Life:

Physical................. 12.33 years

Biological............... 12 days

Effective................ 12 days

Radiation Emitted: (-

Energy of Radiation (keV):

18.6 (max) 5.7 (mean)

Maximum Range of Beta Particles:

Air...................... 6 mm

Water................... 0.006 mm

RADIATION BIOLOGY

Critical Organ: Whole Body

Toxicity: Low Maximum Permissible Body Burden: 1,000 (Ci

Bioassay: Urinalysis required within 10 working days after working with 25 mCi or more of organically bound tritium or with 100 mCi or more of tritiated water or sodium borohydride.

HEALTH PHYSICS

DAC in Air ((Ci/ml): 2 x 10-5 tritium gas or tritiated water (HT, T2, HTO, T2O)

Effluents: Air.............. 1 x 10-7 (Ci/ml

Effluents: Sewer........... 1 x 10-2 monthly (Ci/ml

Survey Technique: Wipes, Counted by LSC or windowless gas counter

Shielding: None

Film Badge Required: In Restricted Areas

Special Considerations: Tritium cannot be monitored directly because of the low beta energy. Special care is needed to control contamination. Regular monitoring by wipe testing is advisable. External contamination does not cause a radiation dose itself but can lead to potentially hazardous internal contamination or can interfere with experimental results. DNA precursors (e.g. 3H thymidine) have unspecified ALI's. (ref. ICRP 30)

Figure 3 14C (Carbon-14)

PHYSICAL CHARACTERISTICS

Half Life:

Physical............. 5,730 years

Biological .... 10 days (whole body) 12 days (fat)

Effective............ 10 days (whole body) 12 days (fat)

Radiation Emitted: (-

Energy Radiation (keV):

156 (max)

49.5 (mean)

Maximum Range of Beta Particles:

Air................... 22.4 mm

Water................. 0.28 mm RADIATION BIOLOGY

Critical Organ: Whole Body and Fat, Soluble form

Toxicity: Medium/Low

Maximum Permissible Body Burden: 400 (Ci (Whole Body) 300 (Ci (fat)

Bioassay: Not routinely done. Urinalysis and breath analysis are possible.

HEALTH PHYSICS

DAC in Air ((Ci/ml): 1 x 10-6 (other than CO or CO2)

Effluents: Air .... 3 x 10-7 (Ci/ml as CO2

Effluents: Sewer............. 3 x 10-4 (Ci/ml monthly

Survey Technique: Beta scintillation survey meter; thin-window GM or proportional survey meter; and wipes counted by LSC.

Shielding: 1 cm Plexiglas (3 mm would be OK, but has poor mechanical properties).

Film Badge Required: In Restricted Areas

Special Considerations: Potential for release of volatile metabolites or reaction products, e.g. CO2. Labeled compounds may concentrate in specific body tissues if ingested. Some organic labeled solvents may penetrate gloves and skin.

Figure 4 32P (Phosphorus-32)

PHYSICAL CHARACTERISTICS

Half Life:

Physical................... 14.28 days

Biological................ 257 days (whole body) 1,157 days (bone) 18 days (liver) 257 days (brain)

Effective.................. 13.5 days (whole body) 14.1 days (bone) 8 days (liver) 3.5 days (brain)

Radiation Emitted: (- and Bremsstrahlung

Energy of Radiation (keV):

1,709 (max)

695 (mean)

Maximum Range of Beta Particles:

Air.................... 620 cm (20 ft)

Water................. 0.8 cm

Lucite................. 0.69 cm

RADIATION BIOLOGY

Critical Organ: Bone (transportable forms), Lung or LLI (ingested insoluble forms)

Toxicity: Medium/Low

Maximum Permissible Body Burden: 30 (Ci (whole body) 6 (Ci (bone)

Bioassay: Urinalysis is possible, most effective 1 - 12 hrs after handling

Dose-Rate at 1 Meter from a 1 mCi Point Source: 0.1 mrem/hr (unshielded)

Dose-Rate to Basal Cells from 1 (Ci/cm2 on skin: 9200 mrem/hr (0.007 cm tissue depth)

Dose-Rate at mouth of Dupont Combi-vial containing 1 mCi in 1 ml liquid: 26000 mrem/hr

HEALTH PHYSICS

DAC in Air ((Ci/ml): 4 x 10-7 (most compounds) Effluents: Air................. 1 x 10-9 (Ci/ml

Effluents: Sewer................ 9 x 10-5 (Ci/ml monthly

Survey Technique: Beta Survey Meter

Shielding: 1 cm Plexiglas; lead may also be needed for millicurie quantities

Film Badge Required: Yes - whole body and ring

Special Considerations: Highest energy radionuclide commonly used in research labs. In addition to good lab practices, use of leaded rubber gloves may be appropriate. Also, absorption of high energy beta by high density materials gives rise to high intensity bremsstrahlung which requires lead shielding, particularly when 10 mCi or more is present. Always remember that high shallow doses can occur from even brief close range exposures to small quantities. Protective glasses and double-gloving are recommended.

Transportable 32P is a bone seeker, special care must be taken to minimize any chance of introducing this isotope into the body. Prompt cleanup of spills is needed to limit airborne activity.

Figure 5 35S (Sulfur-35)

PHYSICAL CHARACTERISTICS

Half Life:

Physical................ 87.5 days

Biological............. 90 days (whole body) 623 days (testis)

Effective.............. 44.3 days (whole body) 76.4 days (testis)

Radiation Emitted: (-

Energy of Radiation (keV):

167 (max)

49 (mean)

Maximum Range of Beta Particles:

Air .... 26 cm (1 ft)

Water.................. 0.32 mm

RADIATION BIOLOGY

Critical Organ: Whole Body or Testis (transportable forms), Lung or LLI (insoluble)

Toxicity: Medium/Low

Maximum Permissible Body Burden: 400 (Ci Whole Body, 90 (Ci Testis

Bioassay: Urinalysis possible

HEALTH PHYSICS

DAC in Air ((Ci/ml): 6 x 10-6 vapor

Effluents: Air..................... 2 x 10-8 (Ci/ml

Effluents: Sewer.................. 1 x 10-3 (Ci/ml monthly

Survey Technique: Thin-window Beta survey meters; and wipes, counted by LSC or gas proportional counter

Shielding: 1 cm Plexiglas (3 mm would be OK, but has poor mechanical properties).

Film Badge Required: In Restricted Areas

Special Considerations: Organic compounds are often strongly retained and ingestion limits have not been set. Gaseous by-products are possible in chemical reactions. 35S-Amino acids may break down in storage or usage to release gaseous products and lead to contamination of surfaces in incubators, etc. Special containment or ventilated enclosures may be necessary.

Figure 6 125I (Iodine-125)

PHYSICAL CHARACTERISTICS

Half Life:

Physical.................... 60.14 days

Biological.................. 138 days (whole body) 138 days (thyroid)

Effective................... 41.8 days (whole body) 41.8 days (thyroid)

Radiation Emitted: (and X-rays, conversion electrons

Energy of Radiation (keV):

35.5 (7% emitted, 93% converted)

27-32 (138%, Te-X-rays)

17.9 e-

Dose Rate at 1 meter from a 1 mCi Point Source: 0.15 mrem/hr

RADIATION BIOLOGY

Critical Organ: Thyroid

Toxicity: Medium/High

Maximum Permissible Body Burden: 6.0 (Ci (whole body) -See MURSOM, Chapter V

Bioassay: Routine thyroid counts required whenever work with unsealed radioiodine in amounts greater than -

VOLATILE FORM

Open Bench.................. 1 mCi

Fume Hood................. 10 mCi

Glove Box................. 100 mCi

BOUND TO NON-VOLATILE COMPOUND

Open Bench................. 10 mCi

Fume Hood................ 100 mCi

Glove Box................ 1000 mCi

Bioassay will normally be required whenever work with > 10% of above values so as to maintain exposures ALARA.

HEALTH PHYSICS

DAC in Air ((Ci/ml): 3 x 10-8 all forms

Effluents: Air............................ 3 x 10-10 (Ci/ml

Effluents: Sewer......................... 2 x 10-5 (Ci/ml monthly

Survey Techniques: Low energy Gamma/X-ray scintillation survey meter; wipe tests

Shielding: 0.1 mm of lead provides 94% attenuation, 0.02 mm = Pb HVL

Film Badge Required: Whole body and ring (see MURSOM)

Special Considerations: Volatilization is a problem. Simply opening a vial of sodium iodide can cause significant airborne release. Solutions should not be made acidic or stored frozen, as this increases volatilization. Work above 10 (Ci is normally recommended to be done in an approved hood. Supplemental "mini hoods", glove boxes, and/or in-line exhaust filters may be required for use and/or storage of volatile forms.

Double gloving strongly recommended. Notify URSO immediately if personnel contamination is suspected. Medical consultation may be needed. Stabilize all spills with solution of 0.1M NaI, 0.1M NaOH, and 0.1M $Na_2S_2O_3$ (sodium thiosulfate) before clean-up.

Figure 7 131I (Iodine-131)

PHYSICAL CHARACTERISTICS

Half Life:

Physical.................... 8.0 days

Biological.................. 138 days (whole body) 7.6 days (thyroid)

Effective................... 7.6 days (whole body) 7.6 days (thyroid)

Radiation Emitted: (and (

Energy of Radiation (keV):

(- 807 (max)

182 (mean)

(- 80 (2.4%)

284 (5.9%)

364 (81.8%)

637 (7.2%)

723 (1.8%)

mean:382 keV

Dose Rate at 1 meter from a 1 mCi Point Source: 0.22 mR/hr

RADIATION BIOLOGY

Critical Organ: Thyroid

Toxicity: Medium/High

Maximum Permissible Body Burden: 0.7 (Ci transportable form -see MURSOM, Chapter V

Bioassay: Routine thyroid counts required whenever working with unsealed radioiodine in amounts greater than -

VOLATILE FORM

Open Bench........................ 1 mCi

Fume Hood....................... 10 mCi

Glove Box....................... 100 mCi

BOUND TO NON-VOLATILE COMPOUND

Open Bench....................... 10 mCi

Fume Hood...................... 100 mCi

Glove Box...................... 1000 mCi

Bioassay will normally be required whenever work with > 10% of above values so as to maintain exposures ALARA.

HEALTH PHYSICS

DAC in Air ((Ci/ml): 2 x 10-8

Effluent: Air........................ 2 x 10-10 (Ci/ml

Effluent: Sewer...................... 1 x 10-5 (Ci/ml monthly

Survey Technique: Beta or Gamma survey meters, and wipe tests

Shielding: 12 mm of lead provides 94% attenuation, Pb HVL = 2.4 mm

Film Badge Required: Whole body and ring (see MURSOM, Chapter V)

Special Considerations: Volatilization is a problem. Simply opening a vial of sodium iodide can cause significant airborne release. Solutions should not be made acidic or stored frozen, as this increases volatilization. All work above 10 (Ci is normally recommended to be done in an approved hood. Supplemental "mini hoods", glove boxes, and/or in-line exhaust filters may be required for use and/or storage of volatile forms.

Double gloving strongly recommended. Notify URSO immediately if personnel contamination is suspected. Medical consultation may be needed. Stabilize all spills with solution of 0.1M NaI, 0.1M NaOH, and 0.1M Na2S2O3 (sodium thiosulfate) before clean-up.

EMERGENCIES INVOLVING RADIOACTIVE MATERIAL

- Rules of thumb for dealing with any emergency involving radioactive material:
- Prevent injury and radiation exposure to personnel.
- Prevent spread of contamination.
- Protect equipment from damage, if possible consistent with the above.
- If airborne radioactive is likely, turn off all fans, and other obvious sources of air circulation, except for radioisotope hoods.
- Identify and quantify the contaminant.
- Obtain Radiation Safety Office assistance.
- Accomplish decontamination of facility under supervision of radiation safety staff.

NOTE: "Emergency Procedures" are posted in each authorized radioisotope facility and are discussed on the following pages from Chapter V of the Marshall University Radiation Safety and Operations Manual (MURSOM).

EMERGENCY PROCEDURES

Life Saving first aid measures should be administered while minimizing spread of contamination from radioisotopes.

All cases of personal or work areas contamination should be documented and reported to the Authorized User and the RSO or his designee. The person responsible for the radioactive material spill is responsible for initiation of the emergency procedure and for performing all or part of the decontamination as directed by the Authorized User and the RSO. Radioactive materials spills are defined in two categories: major and minor; however, there is no sharp transition between them since many variables are involved. The Authorized User should plan with the RSO or his designee in advance for decision levels suitable for the radiochemicals, physical forms, and areas involved.

MAJOR SPILLS

CLEAR AREA: notify persons not involved to vacate room.

PREVENT SPREAD: limit the spill with absorbent paper or pads do not attempt to clean but confine spill; confine potentially contaminated personnel in a safe area. SHIELD SOURCE: shield spill only if no further contamination or significant increase in personal radiation exposure is probable.

SECURE ROOM: vacate and lock facility to prevent entry by unauthorized personnel. Post the facility as contaminated, as soon as possible.

REPORT: notify immediately the Radiation Safety Coordinator (RSC) and the Radiation Safety Officer (RSO) or their designees, and follow instructions.

PERSONNEL DECONTAMINATION: remove contaminated clothing and store in clean labeled plastic bags with the tops twisted and sealed with radioactive warning tape, until the clothing can be evaluated by the RSO or his designee. If spilled on skin, flush thoroughly with water and then wash gently with mild soap and warm water. Survey with appropriate survey meter for residual contamination. (See Decontamination Procedures from Chapter 5 of MURSOM)

MINOR SPILLS

NOTIFY AREA PERSONNEL: notify persons in area spill has occurred.

PREVENT SPREAD: limit the spill with absorbent paper.

CLEAN AREA: with caution (using protective disposable gloves or decontaminateable tongs) fold cleaning papers or pads, and insert into plastic bag; to seal bag twist top and wrap with two layers of tape, fold over twisted top and wrap with two more layers of radioactive warning tape. Label and dispose of sealed bag as solid radioactive waste. Check tools for contamination and clean, or segregate in bags for evaluation.

SURVEY: with a suitable survey meter, check area around spill, hands, feet and clothing for contamination.

REPORT: notify Radiation Safety Coordinator of incident who will report to the RSO or his designee.

DECONTAMINATION PROCEDURES

1. Decontamination of Personnel

The objective of personnel decontamination is to reduce radiation exposure promptly, minimize absorption of radionuclides into the body, and keep localized contamination from spreading. A suitable survey instrument is necessary. Additional information on decontamination may be found in the Radiological Health Handbook at the URSO.

If a person is found to have radioactive contamination on their clothing or body, the following steps should be taken:

Skin

a. Remove any clothing found to be contaminated before determining levels of skin contamination. Generally, levels below 0.1 mrem/hr present a minimal hazard, but still should be removed if possible.

b. Specific hot spots or areas on the skin should be located with a survey meter. These should be cleaned so as to prevent the spread of contamination to clean areas of the body.

c. Ordinarily, soap and lukewarm water (or detergent) will remove most of the contamination.

(1) Wash for 1-2 minutes, rinse and dry the areas. Pay particular attention to the hands and fingernails. Monitor with a survey meter. Repeat if contamination still present.

(2) If contamination still present, wash again using plenty of soap and soft brush. Apply only light pressure to the brush. Rinse, dry and resurvey. Repeat if contamination still present.

(3) Take care to keep radioactivity from being washed into any skin breaks near the contaminated area. Covering the skin break with a sterile bandage may help.

(4) Even if contamination still persists, these efforts should be halted before the skin becomes reddened and irritated.

(5) ALWAYS contact the RSO or his designee, for advice and final monitoring. Wipe tests of the skin after decontamination will supplement survey meter readings for report requirements, in most cases.

d. If contamination is widespread over the body, shower with soap and water, dry and repeat survey. If contamination is still widespread, shower with scrubbing, dry and resurvey. If contamination still exists, select the most highly contaminated areas and proceed as in c. (1) and c. (2). Never let the skin become irritated.

e. DO NOT use organic solvents. These may only increase the probability of radioactive material penetrating the skin.

f. When decontamination is completed, apply lanolin or hand cream to prevent chapping.

g. Notify the RSO or his designee if any difficulty is encountered in removing the contamination, or if assistance in monitoring is desired. The RSO or his designee should provide final monitoring.

Hair

h. If the hair is contaminated, try up to three washings with liquid soap and rinse water. Use towels to keep water from running onto the face and shoulders.

i. Notify the RSO if any difficulty is encountered in removing the contamination or if assistance or monitoring is desired. The RSO or his designee should provide final monitoring.

Clothes

j. Contaminated clothes (or shoes) should be removed from the body to prevent further spread of the contamination. Place these items in plastic bags or containers, for RSO inspection.

k. After necessary body decontamination has been accomplished, and RSO approval obtained, put on protective gloves and lab coat (or surgical gown) and rinse the clothing in a Radioactive Waste Sink (providing the sink is less contaminated than clothing).

l. If several washings still are not able to lower the contamination then either hold it for decay if the half-life is short, or treat it as solid radioactive waste (see Section "Radioactive Waste Disposal").

m. The RSO or his designee will provide final monitoring and advice.

2. Decontamination of Laboratories

This job will be much easier if appropriate planning and precautions are made ahead of time.

a. The general procedure is to confine the radioactive material as much as possible and prevent spread to other areas.

b. Prepare yourself for this job by putting on protective gloves, lab coat or surgical gown, and shoe covers if the floor is contaminated. Wear your personal dosimeter(s).

c. A suitable survey instrument is a must; otherwise you are only guessing where the contamination lies.

d. First remove the gross contamination caused by the spill; start at the edges of the contaminated area and work inward. If a large amount of gamma or high energy beta emitter has been spilled (example: an animal vomits shortly after receiving an oral dose of 15.0 mCi I-131) manipulate the cleaning rags or towels with long forceps or tongs; this will significantly reduce hand exposure. Once a cleaning rag has become contaminated, it should be disposed rather than reused.

e. After removing spilled liquids or other material, soap and water should usually be tried first to remove the remainder of the contamination, or a commercial decontaminant spray may be used. If the spilled material is radioiodine, a solution of 0.1M NaI, 0.1M NaOH and 0.1M Na2S2O3 may be used for iodine stabilization prior to use of detergent.

f. All waste material should be placed in a plastic bag or other container to prevent recontaminating the area. The waste must eventually be sealed in plastic bags as described in section on "Radioactive Waste Disposal".

g. The individual involved in the spill is responsible for the clean up. DO NOT CALL HOUSEKEEPING TO CLEAN UP RADIOACTIVE SPILLS.

h. The RSO will advise in the clean-up procedures and will provide final monitoring.

<u>FEDERAL REGULATIONS</u>

Many details of United States Nuclear Regulatory Commissions' (NRC) rules and regulations governing the License are contained in Title 10, Chapter 1, Code of Federal Regulations Part 19 and 20 (10 CFR 19 and 10 CFR 20). Part 19 establishes format for notices, instructions, and reports by licensees to individuals participating in licensed activities, together with provisions for commission inspections of licensees to ascertain compliance. Part 20 prescribes and establishes standards for protection against radiation hazards arising out of activities under licenses issued by the NRC. Copies of these, and other pertinent parts of the CFR are available and may be examined at the University Radiation Safety Office.

STATE REGULATIONS

The West Virginia Bureau of Public Health (W.V.B.P.H.) has established certain Radiological Health Regulations to protect the public health and safety. These regulations apply to all persons in West Virginia who receive, possess, use, transfer, own or acquire any source of ionizing radiation, including naturally occurring radioactive materials, accelerator produced radioactive materials, and X-ray producing devices. The regulations provide for the registration and applicable safety requirements of all said sources. Registration is made on forms available from W.V.B.P.H. Registration does not imply W.V.B.P.H. approval or disapproval of the use of such registrable items. Pertinent details may be obtained from the RSO.

<u>DEFINITIONS</u> Some of the terms that are commonly used in nuclear science and law are defined or explained in this chapter. Other terms not defined here may be found in the literature cited1, or in Title 10 of the Code of Federal regulations, Chapter I, part 20, paragraph 20.1003.

Absorbed dose - When IONIZING RADIATION passes through MATTER, some of its energy is imparted to the matter. The amount absorbed per unit mass of irradiated material is called the absorbed dose, and is measured in rads.

Absorber - Any Material that absorbs or diminishes the intensity of ionizing RADIATION. Neutron absorbers, like boron, hafnium, and cadmium, are used in control rods for reactors. Concrete and steel absorb gamma rays and neutrons in reactor shields. A thin sheet of paper or metal will absorb or attenuate alpha particles.

Airborne Radioactivity Area - A place where airborne radioactivity exists (1) in excess of DAC limits, or (2) where an individual could exceed an intake of 0.6% ALI in a week during the hours an individual is present; equivalent to (2000 hrs/yr) (DAC) (0.006) = 12 DAC-HRS

Airborne Radioactive Material - Any airborne radioactive material dispersed in the air in the form of dusts, fumes, mists, vapors or gases.

ALI - Acronym for Annual Limit on Intake

Alpha Particle - A positively charged particle emitted by certain radioactive materials. It is made up of two neutrons and two protons bound together, hence is identical with the nucleus of a helium atom. It is not dangerous to plants, animals or man unless the alpha-emitting substance has entered the body.

Annual Limit on Intake - The calculated value of adult intake, by inhalation or ingestion, which would result in a CEDE of 5 rems whole body or a CDE of 50 rems to a single organ or tissue, which ever is smaller.

Attenuation - The decrease in exposure rate of radiation caused by passage through material.

Authorized User - A person authorized and named on the NRC License, or meeting the experience and training criteria of 10 CFR 33.15 and authorized by the RSO and RSC of the University, to use radioactive material for teaching and/or research; and/or to supervise such use by others under specific conditions.

Background Radiation - The radiation in man's natural environment, including cosmic rays and global fallout and radiation from the naturally radioactive elements, both outside and inside the bodies of men and animals. It is also called natural radiation, natural background, or just "background".

Barn - A unit area used in expressing the cross sections of atoms, nuclei, electrons, and other particles. One barn is equal to 10-24 square centimeter.

Becquerel - One nuclear transformation or disintegration per second (1 Ci = 37 x 109 Bq). ________________ 1 Glossary of Atomic Terms, Technical Writers' Section, Public Relation Branch U.K. Atomic Energy Authority London (1966). Glossary of Terms Frequently Used in Nuclear Physics, Sach and Schwarts, American Institute of Physics, New York (1961)

Beta Particle - An elementary particle emitted from a nucleus during radioactive decay, with a single electrical charge and a mass equal to 1/1837 that of a proton. A negatively charged beta particle is identical to an electron. A positively charged beta particle is called a positron.

Biological Dose - The damage from a radiation dose absorbed in biological matter, measured in rems.

Byproduct Material - Any radioactive material (except special nuclear material) yielded in or made radioactive by exposure to the radiation incident to the process of producing or utilizing special nuclear material.

Calendar Quarter - Not less than 12 consecutive weeks nor more than 14 consecutive weeks. The first calendar quarter of each year shall begin in January and subsequent calendar quarters shall be such that no day is included in more than one calendar quarter or omitted from inclusion within a calendar quarter. No licensee shall change the method observed by him of determining calendar quarters except at the beginning of a calendar year.

CDE - Acronym for Committed Dose Equivalent

Committed Dose Equivalent (HT,50) - Dose equivalent to an organ or tissue of reference (T) during the next 50 years following an intake.

CEDE - Acronym for Committed Effective Dose Equivalent

Cerenkov Radiation - Light emitted when charged particles pass through a transparent material at a velocity greater than that of light in that material.

Charged Particle - An elementary particle that carries a positive or negative electric charge.

Class, lung class, or inhalation class - Classification of inhaled material according to its rate of clearance from the pulmonary region of the lung: D = < 10 Days, W = Weeks (10 to 100 days), Y = Years (> 100 days).

Committed Effective Dose Equivalent (HE,50) - The sum of the risk weighted CDE's of the various body organs. Weighting factors (WT) are given in the regulations. CEDE is a whole body dose for radioactive intakes. CEDE = HE,50 = (wTHT,50

Curie - The basic unit to describe the intensity of radioactivity in a sample of material. The curie is equal to 37 billion disintegrations per seconds, which is approximately the rate of decay of one gram of radium.

DAC - Acronym for Derived Air Concentration

DAC -hr - The fraction or multiple of the DAC times the number of hours of intake at that concentration. (2000 DAC-hrs of light work yields 1 ALI intake)

DDE - Acronym for Deep Dose Equivalent

Declared Pregnant Woman - A worker who has voluntarily informed her employer in writing of her pregnancy and the estimated conception date. Dose limits for the embryo/fetus then apply.

Deep Dose Equivalent (HD) - rem dose for external whole body radiation calculated at a depth of one centimeter (1 cm).

Derived Air Concentration - The calculated concentration of a radionuclide that will result in an intake of one (1) ALI during one work year, for the "reference" man doing "light work". (2000 hrs/yr) (1.2 m3/hr) (DAC) = 1.0 ALI

Dose Equivalent (HT) - The rem tissue dose, calculated as rads times quality factor times other modifying factors at the location of interest. Usually preceded by other words (e.g. deep, committed, etc.).

Dose - Means the quantity of radiation absorbed, per unit of mass, by the body or by any portion of the body. When these regulations specify a dose during a period of time the dose means the total quantity of radiation absorbed per unit of mass, by the body or by any portion of the body during such period of time.

Effective Dose Equivalent (HE) - The sum of the products of dose equivalents to various tissues (HT) times the weighting factors (wT) assigned to the tissues. HE = (wTHT

Electron volt (eV) - The amount of kinetic energy gained by an electron when it is accelerated through an electric potential difference of one volt. It is equivalent to 1.602 x 10-12 erg, or 1.602 x 10-19 joule of energy.

Entrance or Access Point - Any portal through which an individual could gain access to radiation areas or to radioactive material, regardless of the intended use of the portal.

Eye Dose Equivalent - External radiation dose to lens of eye at a tissue depth of 0.3 cm = 3 mm = 300 mg/cm2.

Fluorescence - Many substances can absorb energy (as from X-rays, ultraviolet light, or radioactive particles), and immediately emit this energy as an electromagnetic photon, often of visible light. This emission is fluorescence.

Gamma Rays - High-energy, short-wave length electromagnetic radiation. Gamma radiation frequently accompanies alpha and beta emissions and always accompanies fission. Gamma rays originate in the nucleus of an atom.

Geiger-Muller Counter - A type of radiation detection and measuring instrument commonly used for radiation surveys. It is practical when its limitations are understood.

Half-life, Effective - The time required for a radionuclide contained in a biological system, such as a man or an animal, to reduce its activity by half as a combined result of radioactive decay and biological elimination.

Half-thickness - The thickness of any given absorber that will reduce the intensity of a beam of radiation of one-half its initial value.

Half-life - The time in which half the atoms of a particular radioactive substance disintegrate to another nuclear form. Measured half-lives vary from millionths of a second to billions of years.

Half-life Biological - The time required for a biological system, such as a man or an animal, to eliminate, by natural processes, half the amount of a substance (such as a radioactive material) that has entered it.

High Radiation Area - Accessible area with greater than 100 mrem/hr at 30 cm (1 foot) from a source or enclosure.

Human use - Means the internal or external administration of radiation or radioactive materials to an individual.

Interlock - Means a device for precluding access to an area of radiation hazard either by preventing entry or by automatically shutting down the source of the hazard.

Internal Dose - The dose equivalent from intake of radioactive material into the body.

Ionization radiation - Any radiation displacing electrons from atoms or molecules, thereby producing ions. Ionizing radiation may produce severe skin or tissue damage.

Ionization chamber - An instrument that detects and measures ionizing radiation exposure by measuring the electrical current that flows when radiation ionizes gas in a chamber, making the gas a conductor of the electricity. Air is the most common gas in the chamber.

Ionizing Radiation Producing Devices - Means any equipment capable of producing ionizing radiation when the associated controls are operated, but excluding equipment which produces radiation only by the use of radioactive materials.

Isotope - Atomic nuclei with the same number of protons but different number of neutrons.

Licensed Material - Source material, special nuclear material, or byproduct material received, possessed, used or transferred under a general or specific license issued by the Nuclear Regulatory Commission.

Lost or Missing - Location unknown, including items shipped but not delivered and not readily traceable in transport.

Luminescence - Emission of light produced by the action of biological or chemical processes or by radiation, or any other cause except high temperature (which produces incandescence).

MeV - One million (or 106) electron volts.

Monitoring - Means a periodic or continuous determination of the exposure or dose rate in an area (area monitoring) or the exposure received by a person (personnel monitoring) or the measurement of contamination level.

Neutron Flux - A measure of the intensity of neutron radiation. It is the number of neutrons passing through one square centimeter of a given target in one second.

Nonstochastic Effect - Health effects which seem to have a threshold dose and increase in severity with increasing dose (e.g. cataracts)

Nuclide - A general term applicable to all atomic forms of the elements. The term is often erroneously used as a synonym for "isotope", which properly has a more limited definition.

Occupational Dose - Any dose above background radiation to an individual from radiation (1) in a restricted area or (2) in the course of employment in which the individual's duties involve exposure to ionizing radiation; provided, however, that occupational dose does not to include an individual's radiation dose for the purpose of diagnosis or therapy as a patient, or as a volunteer medical research subject.

Personnel Monitoring Equipment - Devices designed to be worn or carried by an individual for the purpose of measuring the radiation dose or exposure received (e.g., film badges, pocket chambers, pocket dosimeters, TLD rings, etc.).

Phosphor - A luminescent substance; a material capable of emitting light when stimulated by radiation.

Photon - The carrier of a quantum of electromagnetic energy. Photons have an effective momentum but no mass or electrical charge.

Rad - (Acronym for radiation absorbed dose.) The basic unit of absorbed dose of ionizing radiation. A dose of one rad means the absorption of 100 ergs of radiation energy per gram of absorbing material, or 0.01 Joule per kilogram of absorber.

Radiation Area - Accessible area with greater than 5 mrem/hr at 30 cm (1 foot) from a source or enclosure.

Radiation Standards - Exposure standards, permissible concentrations, rules for safe handling, regulations for transportation, regulations for laboratory or industrial control of radiation, and control of radiation exposure.

Radiation - Gamma rays and X-ray, alpha and beta particles, high-speed electrons, neutrons and other nuclear particles; but not sound or radio waves or visible, infrared, or ultraviolet light. (Same as ionizing radiation for purposes of this manual).

Radioactive Standard - A sample of radioactive material, usually with a long half-life, in which the number and type of radioactive atoms at a definite reference time is known.

Radioisotope - A radioactive isotope. An unstable isotope of an element that decays or disintegrates spontaneously, emitting radiation.

Radioluminescence - Visible light caused by radiations from radioactive substances; an example is the glow from luminous paint containing radium and crystals of zinc sulfide, which give off light when struck by alpha particles from the radium.

Rem - (Acronym for roentgen equivalent man.) The unit of dose equivalent of any ionizing radiation; 1 rem of dose produces the same biological effect as a unit of absorbed dose (1 rad) of ordinary X-rays. (See Dose Equivalent)

Restricted Area - (Enforced as an area under locked or constantly supervised access restriction) where access is limited to protect "individuals from undue exposure to radiation and radioactive material".

Roentgen - (Abbreviation R) A unit of exposure to ionizing radiation. It is that amount of gamma or X-rays required to produce ions carrying one electrostatic unit of electrical charge (either positive or negative) in one cubic centimeter of dry air under standard conditions.

Scintillation Counter - An instrument that detects and measures ionizing radiation by analysis of the light produced when the radiation impinges on certain light producing materials (phosphors).

Sealed Source - Means radioactive material that is permanently bonded or fixed in a capsule or matrix designed to prevent release and dispersal of the radioactive material under the most severe conditions which are likely to be encountered in normal use and handling.

Shallow Dose Equivalent (HS) - The dose equivalent at a tissue depth of 0.007 cm = 0.07 mm = 7 mg/cm2 averaged over an area of one cm2.

Site Boundary - Legal line where ownership, lease, or control of the property or land ends.

Source Material - Means: (1) Uranium or thorium, or any combination thereof, in any physical or chemical form or (2) Ores which contain by weight one-twentieth of one percent (0.05 percent) or more of uranium, thorium or any combination thereof, except special nuclear material.

Special Nuclear Material - In atomic energy law, this term refers to plutonium, uranium-233, uranium containing more than the natural abundance of uranium 233 or uranium-235, or any material artificially enriched in any of these substances.

Stochastic Effect - Health effects that occur randomly and for which the probability of occurrence is a linear function of dose without threshold (e.g. cancer, mutation). The severity of the effect is not dependent on dose.

Survey - Means the evaluation of the radiation associated with the production, use, release, disposal or presence of sources of radiation under a specific set of conditions. When appropriate, such evaluation includes a physical survey of the location of materials and/or equipment and measurements of radiation levels or concentrations of radioactive materials.

TEDE - Acronym for Total Effective Dose Equivalent

Total Effective Dose Equivalent - The sum of DDE (for external) and CEDE (for internal) damage. TEDE = HD + HE,50 = HD + (wTHT,50

Unrestricted Area - Means any area access which is not controlled by the licensee for purposes of protection of individuals from exposure to radiation and radioactive materials, and any area used for residential quarters.

Waste, Radioactive - Equipment and materials (from nuclear operations) which are radioactive and for which there is no further use. Wastes are generally classified as high-level (having radioactivity concentrations of hundreds to thousands of curies per gallon or cubic foot), low-level (in the range of one microcurie per gallon or cubic foot), or intermediate (between these extremes).

Weighting Factor (WT) - The ratio of the radiation risk to a single organ/tissue to the overall risk to the body, from uniform whole body exposure (for stochastic effects, e.g. cancer). NOTE: The sum of the weighting factors for all organs is 1.00 Values are listed in 10 CFR 20.1003 definitions.